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RELATIVE SENSITIVITY TO REINFORCER AMOUNT AND DELAY IN A SELF-CONTROL CHOICE SITUATION

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Rats were exposed to concurrent-chains schedules in which a single variable-interval schedule arranged entry into one of two terminal-link delay periods (fixed-interval schedules). The shorter delay ended with the delivery of a single food pellet; the longer day ended with a larger number of food pellets (two under some conditions and six under others). In Experiment 1, the terminal-link delays were selected so that under all conditions the ratio of delays would exactly equal the ratio of the number of pellets. But the absolute duration of the delays differed across conditions. In one condition, for example, rats chose between one pellet delayed 5 s and six pellets delayed 30 s; in another condition rats chose between one pellet delayed 10 s and six pellets delayed 60 s. The generalized matching law predicts indifference between the two alternatives, assuming that the sensitivity parameters for amount and delay of reinforcement are equal. The rats' choices were, in fact, close to indifference except when the choice was between one pellet delayed 5 s and six pellets delayed 30 s. That deviation from indifference suggests that the sensitivities to amount and delay differ from each other depending on the durations of the delays. In Experiment 2, rats chose between one pellet following a 5-s delay and six pellets following a delay that was systematically increased over sessions to find a point of indifference. Indifference was achieved when the delay to the six pellets was approximately 55 s. These results are consistent with the possibility that the relative sensitivities to amount and delay differ as a function of the delays.

Key words: choice, generalized matching law, sensitivity to reinforcer amount and delay, functional equivalence, concurrent-chains schedules, lever press, rats

Studies of choice between two alternatives differing in amount and delay of reinforcement have shown that reinforcer amount and delay combine multiplicatively (Baum & Rachlin, 1969; cf. Logan, 1965; Navarick & Fantino, 1976), but are not linearly equivalent in their effects on choice (Green & Snyderman, 1980; Ito & Asaki, 1982; Logue, Rodriguez, Peña-Correal, & Mauro, 1984). The generalized matching law (Baum, 1974) can be extended to the situation in which both reinforcer amount and delay are varied by the following equation:

$$\frac{R_1}{R_2} = k\left(\frac{A_1}{A_2}\right)^{S_a}\left(\frac{D_2}{D_1}\right)^{S_d}, \tag{1}$$

where A is the reinforcer amount, D is the delay to the reinforcer, R is the number of responses to that alternative, and k, S_a, and S_d are empirical constants. These parameters can be estimated from the logarithmic transformation of Equation 1, which takes the following form:

$$\log\left(\frac{R_1}{R_2}\right) = S_a\log\left(\frac{A_1}{A_2}\right) + S_d\log\left(\frac{D_2}{D_1}\right) + \log k. \tag{2}$$

A bias is present when k is less than or greater than 1.0. The parameters S_a and S_d represent the sensitivity to variations in reinforcer amount and delay, respectively.

The choice between two alternatives differing in reinforcer amount and delay has been studied within the framework of *self-control* and *impulsiveness* (e.g., Rachlin & Green, 1972). Preference for a larger, delayed reinforcer has been called self-control, whereas preference for a smaller, immediate reinforcer has been called impulsiveness. Several studies have shown that preference between delayed larger and immediate smaller reinforcer changes from the smaller to the larger reinforcer as the delays to both are increased by equal durations (Ainslie, 1974; Green, Fisher, Perlow, & Sherman, 1981; Rachlin & Green, 1972; see also Navarick & Fantino, 1976).

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Sometimes the influence of immediacy seems to diminish due to certain kinds of experiences so that choice may shift to the large delayed reinforcer even though the delays and amounts comprising the choice have not changed. Such changes may be interpreted in terms of differences in sensitivities to reinforcer amount and delay (i.e., to differences between S_a and S_d in Equation 1) (e.g., Grace, 1995; Logue et al., 1984; White & Pipe, 1987). For example, Logue et al. studied pigeons' choices between an immediate, smaller reinforcer and a delayed, larger reinforcer. Some pigeons were trained with a fading procedure (e.g., Mazur & Logue, 1978), and some were trained without a fading procedure. The fading procedure increased the number of choices for the larger, more delayed reinforcers. In an effort to clarify the difference in choice between the fading and nonfading procedures, Logue et al. varied reinforcer amount and delay separately and determined sensitivity values for reinforcer amount and for delay based on the generalized matching equation. As it turned out, when subjects were exposed to the fading procedure, the sensitivity value for reinforcer amount became larger relative to the sensitivity for reinforcer delay. Thus, differences in the sensitivities to reinforcer amount and delay may account for differences in the pattern of choice when a fading or a nonfading procedure was used. Specifically, the relative sensitivities to reinforcer amount and delay (S_a/S_d) was useful in describing the reversal of choice.

A difference line of research also suggests that changes in performance might be understood in terms of differences in the relative sensitivities to reinforcer amount and delay. White and Pipe (1987), using a concurrent-chains schedule, arranged a self-control choice situation and found that pigeons' sensitivity to reinforcer amount (S_a) increased with increases in delay value when both reinforcer amount and delay were varied in a situation similar to one used by Navarick and Fantino (1976), suggesting that preference reversal exhibited in a self-control choice situation may be in part due to changes in sensitivity to reinforcer amount.

Fitting Equation 2 to a set of data is one way to assess the sensitivities to reinforcer amount and delay. Another way is to measure points of indifference—that is, the point at which a subject responds equally often on two alternatives that lead to different combinations of reinforcer amount and delay. A point of indifference specifies how much additional delay each additional reinforcer (e.g., one food pellet) is worth (cf. Ito & Asaki, 1982; Logan, 1965). According to the generalized matching equation, for cases in which A_1/A_2 is equal to D_1/D_2, indifference between two alternatives (i.e., $R_1 = R_2$) can occur when S_a is equal to S_d (including the special case in which S_a and S_d are equal to 1.0), whereas indifference cannot occur when S_a is not equal to S_d. Obtained points of indifference, therefore, can be used to determine some relations, whether the sensitivity values for reinforcer amount and delay (i.e., S_a and S_d) are equal or unequal.

The present study (Experiment 1), using a concurrent-chains schedule with a single VI 30-s initial link, arranged the standard self-control choice situation. Across conditions, the amounts and delays of the reinforcers were varied with the stipulation that the ratio of delays (D_1/D_2) exactly equaled the ratio of amounts (A_1/A_2). Under these conditions, indifference is predicted when S_a is equal to S_d (or both S_a and S_d are equal to 1.0). Experiment 2 attempted to determine the point of indifference between two alternatives that differed in both amount and delay of reinforcement under the delay ratio of 1:6. That is, functionally equivalent combinations of reinforcer amount and delay were found by increasing the delay for the larger reinforcer while the delay for the smaller reinforcer was held constant, as in Ito and Asaki (1982).

EXPERIMENT 1

Method

Subjects

Eight male albino rats, approximately 3 months old at the beginning of the experiment, were housed individually and maintained at about 80% of their free-feeding body weights by supplemental food after each experimental session. They had no experimental histories. Water was continuously available in both the home cage and the chamber.

Apparatus

A chamber (25 cm by 25 cm by 31 cm) with two retractable levers was used. The levers (2 cm wide, 0.2 cm thick) intruded 2 cm into the chamber and were mounted 11.5 cm apart (center to center) and 5 cm above the floor on the front wall. Two 24-Vdc lamps were located above each lever on the front wall. Each lever could be retracted by a 24-Vdc solenoid, during which the lamp for the retracted lever was off. A minimum force of about 0.15 N was required to operate either lever. A recess (5 cm by 5 cm by 2.5 cm) was located 1 cm above the floor on the center of the front wall and was illuminated by a 24-Vdc small lamp for a prescribed period each time a reinforcer (a 45-mg food pellet) was delivered into the recess. A water bottle was mounted on the side wall. The whole chamber was enclosed in a sound-attenuating chest, and masking noise was provided by an exhaust fan. A microcomputer system (NEC PC-8001 and PC-9801CV) controlled the experiment and recorded events.

Procedure

Preliminary training. Rats were initially trained to press the right lever by the method of successive approximations, and then each press on either the right or left lever was reinforced for several sessions. Only one lever (either right or left) was available at any time during preliminary training. Thereafter, each lever press retracted the lever and produced food. To reduce position preferences, the same number of reinforcers was provided for each lever during preliminary training.

Concurrent-chains schedule. A concurrent-chains schedule was then introduced, in which a single variable-interval (VI) schedule arranged access to the terminal links. Each interval of the VI tape was derived from the distribution described by Fleshler and Hoffman (1962). A single VI schedule was used to equate reinforcement rate for two alternatives. In this procedure, the available terminal link was assigned to either the right or the left lever in a quasi-random sequence. This procedure assured an equal number of presentations of each terminal link (e.g., Stubbs & Pliskoff, 1969). When the terminal link became available on either lever, the VI timer stopped operating until after the reinforcer was delivered. Entry into a terminal link occasioned two events: (a) The lever retracted on the side not pressed, and (b) the lamp for the retracted lever was turned off. Further responding on the remaining lever produced food according to a fixed-interval (FI) schedule in that terminal link. When food was delivered, the remaining lever retracted and the lamp was turned off for a period prescribed by reinforcer conditions. Following the reinforcement period, both levers were inserted and another cycle began. The VI timer restarted at this time.

The VI schedule in the initial links was 2 s initially and was then increased to 30 s over several sessions. During this phase, the terminal links were FI 5-s schedules. In the first condition, rats chose between equal reinforcer amounts (one food pellet) under equal terminal-link schedules (FI 5 s). Choice proportions with equal reinforcer amounts did not deviate from .5 by more than .05.

For 3 rats the terminal-link delays were short; for 3 rats the terminal-link delays were long; and the remaining 2 rats (R4 and R5) were exposed to both the short and long terminal-link delays. For each group of rats (short or long), two different pairs of reinforcer delays were combined with two different pairs of reinforcer amounts. For the short-delay (i.e., 5-s delay) group, the two pairs were 5-s versus 10-s delay and 5-s versus 30-s delay, whereas for the long-delay (i.e., 10-s delay) group, the two pairs were 10-s versus 20-s delay and 10-s versus 60-s delay. The pairs of reinforcer amounts used for the two groups were one versus two food pellets and one versus six food pellets, combined so that the ratio of pellets equaled the ratio of delays. Pellets were delivered into the recess at a rate of one per 100 ms. During the reinforcement periods, the recess remained illuminated for a duration proportional to the larger of two reinforcers delivered (2 s per pellet). Therefore, the reinforcement period was 4 s when the reinforcer amount was one or two food pellets and 12 s when it was one or six food pellets.

Four different ratios of reinforcer amounts (i.e., A_1/A_2 = 0.17, 0.5, 2, and 6) were combined with the same ratios of reinforcer delays so as to produce indifference between two alternatives ($R_1 = R_2$), according to Equation 1, if S_a is equal to S_d. According to the

Table 1

Mean number of responses for right (R) and left (L) lever during both initial and terminal links, mean choice proportions for right lever, and standard deviation (in parentheses). The sequence of conditions from top to bottom represents the order of presentation of each condition, and the number of sessions per condition is indicated.

	Delay (s)		Amount (pellets)			Initial-link responses		Terminal-link responses		
Subject	R	L	R	L	Sessions	R	L	R	L	Choice proportion
R1	5	10	1	2	15	383	490	106	260	.44 (.03)
	10	5	2	1	15	496	504	220	155	.50 (.04)
	5	30	1	6	23	276	595	97	566	.32 (.07)
	30	5	6	1	15	533	426	497	127	.56 (.04)
R2	5	30	1	6	18	121	213	58	316	.36 (.02)
	10	5	2	1	15	229	247	105	52	.48 (.01)
	5	10	1	2	14	207	226	57	141	.48 (.01)
	30	5	6	1	15	245	190	284	55	.56 (.03)
R3	30	5	6	1	17	208	96	232	75	.68 (.02)
	5	30	1	6	23	149	219	93	290	.39 (.04)
	10	5	2	1	18	405	241	137	96	.63 (.03)
	5	10	1	2	19	341	290	115	208	.54 (.03)
R4	5	30	1	6	21	93	137	139	261	.41 (.02)
	10	5	2	1	14	257	228	165	40	.53 (.06)
	5	10	1	2	18	173	154	57	126	.53 (.04)
	30	5	6	1	14	160	89	314	43	.64 (.03)
	10	20	1	2	18	200	147	160	276	.58 (.04)
	20	10	2	1	15	138	129	210	105	.52 (.05)
	10	60	1	6	15	267	230	206	689	.54 (.03)
	60	10	6	1	18	349	349	641	202	.50 (.04)
R5	10	60	1	6	14	140	133	88	521	.51 (.02)
	60	10	6	1	17	120	137	544	126	.46 (.05)
	10	20	1	2	18	213	185	149	373	.54 (.03)
	20	10	2	1	15	272	224	392	173	.55 (.03)
	5	30	1	6	26	122	200	89	291	.39 (.05)
	10	5	2	1	15	270	327	209	99	.46 (.06)
	5	10	1	2	16	301	406	100	242	.43 (.04)
	30	5	6	1	21	259	209	371	81	.55 (.03)
R6	20	10	2	1	16	239	223	432	213	.52 (.05)
	10	20	1	2	24	421	589	178	412	.42 (.04)
	60	10	6	1	14	156	172	1,169	254	.48 (.04)
	10	60	1	6	19	330	323	154	1,170	.51 (.03)
R7	10	60	1	6	14	219	225	175	625	.49 (.02)
	20	10	2	1	26	340	333	234	121	.49 (.04)
	10	20	1	2	14	406	428	156	232	.49 (.02)
	60	10	6	1	17	206	263	460	130	.43 (.02)
R8	60	10	6	1	14	253	196	974	180	.56 (.02)
	10	20	1	2	14	551	538	250	567	.50 (.03)
	20	10	2	1	14	769	510	510	200	.60 (.03)
	10	60	1	6	14	343	333	198	808	.52 (.02)

generalized matching equation, for example, indifference would be achieved between two alternatives consisting of one food pellet (A_1) with a 5-s delay (D_1) and six food pellets (A_2) with a 30-s delay (D_2) in the 5-s delay group, because $A_1D_2 = 30$ and $A_2D_1 = 30$ if all parameters in Equation 1 are equal to 1.0. All rats were exposed to four combinations of the ratios of reinforcer amounts and delays in different sequences. The order of conditions and values of delays used are described in the results (see Table 1).

Each condition was continued until the daily choice proportions satisfied the following stability criterion: After 14 days (and every day thereafter until stability was achieved), the choice proportions for the last six sessions were divided into three successive blocks of two sessions. Choice proportions were considered stable when (a) the means of three blocks did not differ from each other by more than 0.05 and (b) there was neither an upward ($M_1 < M_2 < M_3$) nor a downward ($M_1 > M_2 > M_3$) trend in the block means. Each daily session consisted of 30 cycles.

Results

Mean number of responses for both initial and terminal links, mean choice proportions, and standard deviations were calculated over the last six sessions of each condition for each rat. Mean choice proportions were obtained by dividing the initial-link responses for the right lever by the total initial-link responses. These are shown in Table 1, along with the order of presentation of conditions. The sequence of conditions from top to bottom represents the order in which different pairs of reinforcer delays were combined with different pairs of reinforcer amounts. For the rats in the 5-s delay group, choice proportions for the larger reinforcer increased as a function of the reinforcer amount ratios. In contrast, for the rats in the 10-s delay group, choice proportions did not differ substantially from indifference for the four combinations of the reinforcer amount and delay.

Figure 1 shows the log response ratios as a function of the log reinforcer amount (or delay) ratios for each rat in the 5-s delay group. Data were averaged over the last six sessions of each condition. A linear regression was applied to the log-transformed data; that is, $\log(R_1/R_2) = c \log(A_1/A_2) + \log b$ or $\log(R_1/R_2) = c \log(D_2/D_1) + \log b$. In this analysis, the line should be flat if S_a is equal to S_d, but the line should not be flat if S_a is not equal to S_d. The values of the slope (c) of the function ranged from 0.17 to 0.32; the mean slope value across 5 rats was 0.22. This result is consistent with the interpretation that S_a is not equal to S_d in the 5-s delay condition. For all rats, the response ratios increased with increases in the ratios of the reinforcer amounts. Transformed to choice proportions, mean choice proportion for the right lever across each rat were .37, .48, .52, and .60 for the reinforcer amount ratios of 0.17, 0.5, 2, and 6, respectively. Thus, rats preferred the larger reinforcer more when the larger reinforcer was six food pellets (i.e., the reinforcer amount ratios were 0.17 and 6); mean choice proportion for the larger reinforcer was .612 for the reinforcer amount ratios of 0.17 and 6, whereas it was .518 for the reinforcer amount ratios of 0.5 and 2.

Figure 2 shows the log response ratios as a function of the log reinforcer amount (or delay) ratios for each rat in the 10-s delay group. Contrary to the data from the 5-s delay group, the response ratios did not vary as a function of the reinforcer amount ratios. As in Figure 1, a linear regression was applied to the log-transformed data. The values of the slope (c) ranged from -0.06 to 0.09, and the mean slope value across 5 rats was -0.01. This result, contrary to the result shown in Figure 1, is consistent with the interpretation that S_a is equal to S_d in the 10-s delay condition. For most rats, choice proportions were around .5 and did not vary substantially across the four different ratios of reinforcer amounts. Mean choice proportions for the right lever across each rat were .51, .51, .54, and .49 for the reinforcer amount ratios of 0.17, 0.5, 2, and 6, respectively. The results clearly showed that indifference could be achieved between two alternatives consisting of one food pellet with a 10-s delay and two food pellets with a 20-s delay or one food pellet with a 10-s delay and six food pellets with a 60-s delay.

These results were also confirmed by within-subject comparisons (see the data obtained from R4 and R5 under both the 5-s delay and the 10-s delay series). The present results thus are consistent with the view that S_a was equal to S_d under the 10-s delay series but not under the 5-s delay series.

Discussion

The data shown in Figures 1 and 2 suggest that sensitivity values S_a and S_d varied depending on absolute durations of the delay values. The present choice situation is similar to that used by Green and Snyderman (1980) and Snyderman (1983), who arranged conditions in which reinforcer amounts and delays were combined, keeping the reinforcer amount and delay ratios constant but changing the absolute durations of the delays. In one condition of their studies, the reinforcer delay

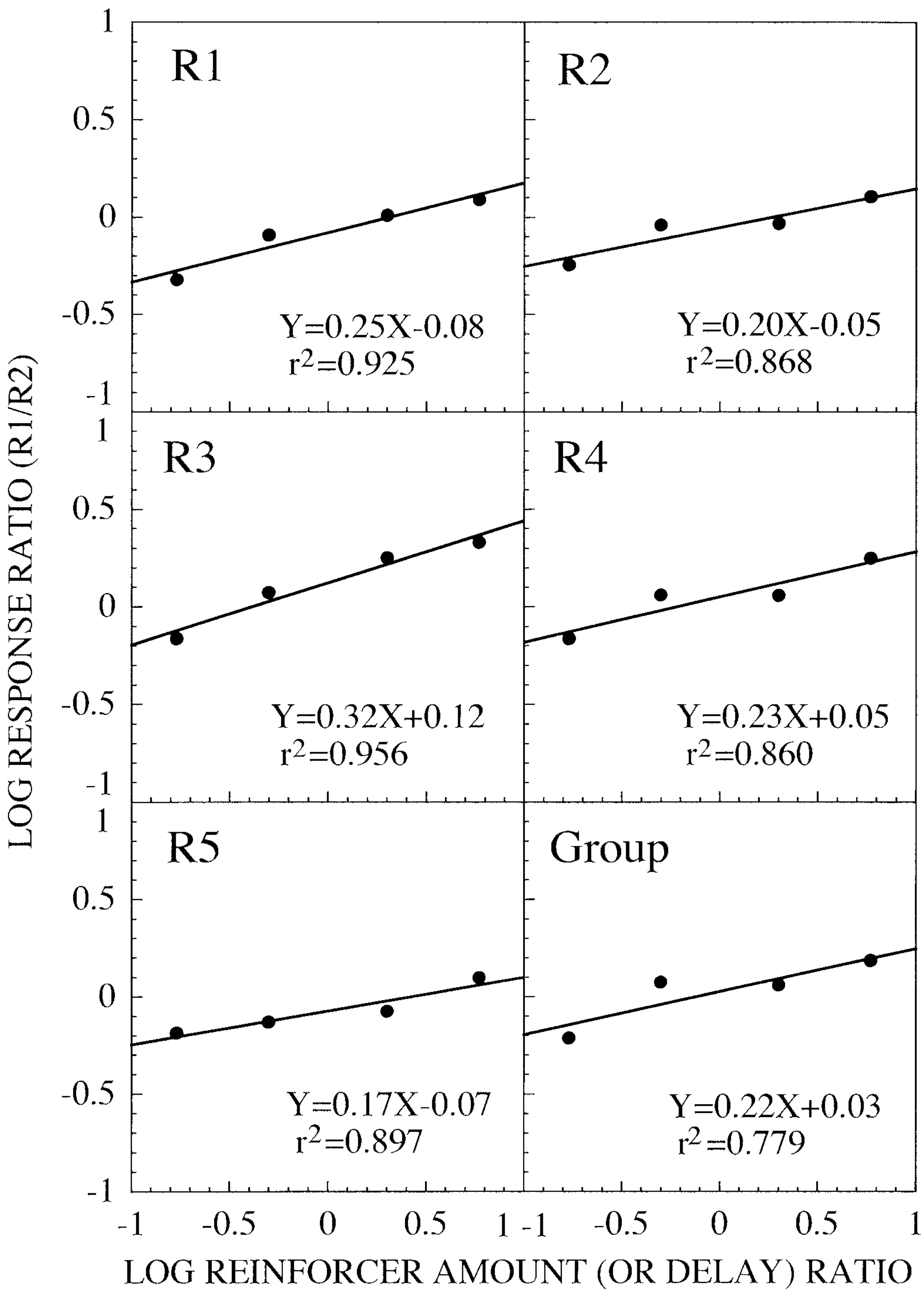

Fig. 1. The log response ratios for the 5-s delay group as a function of the log reinforcer amount (or delay) ratios.

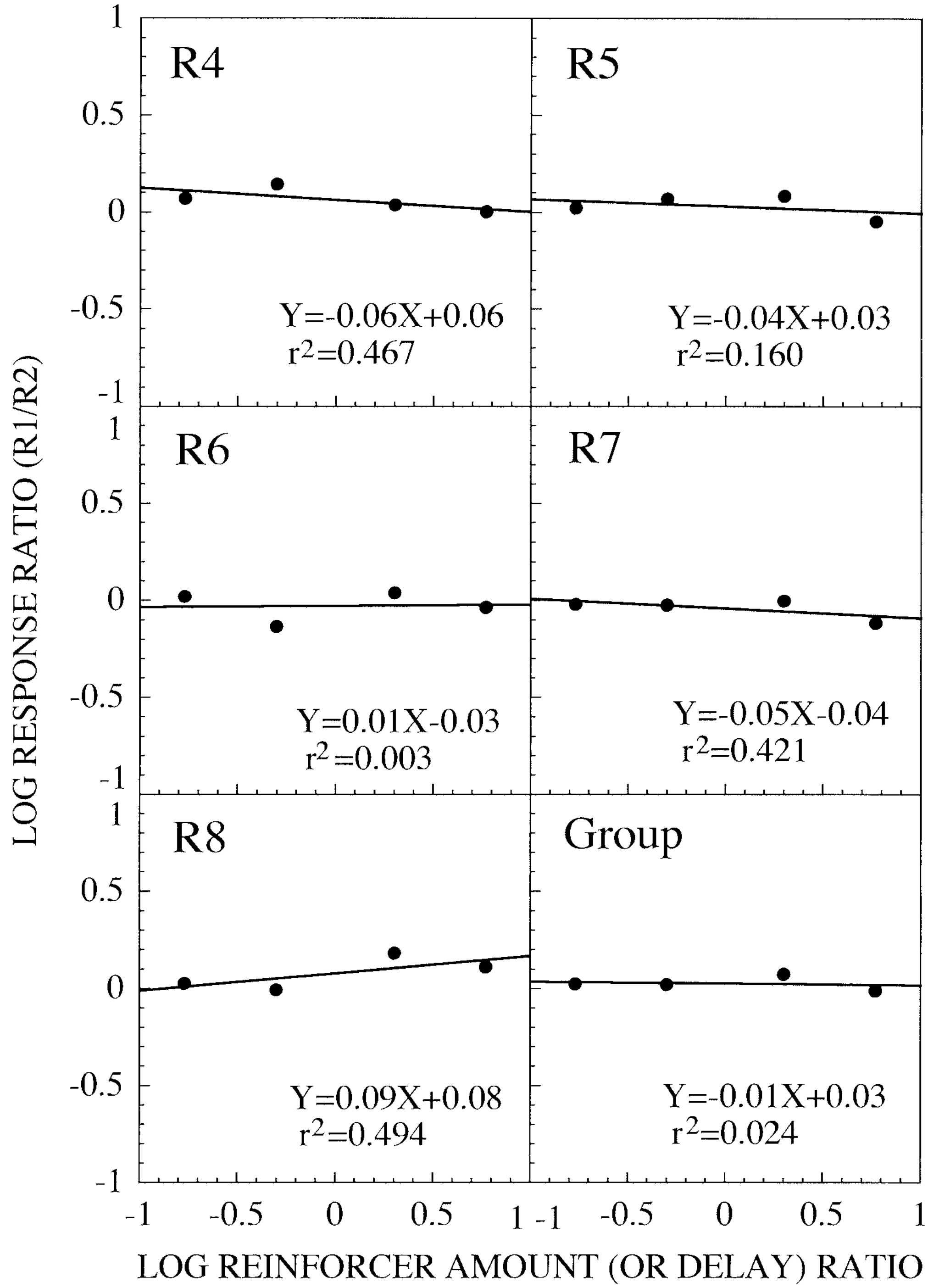

Fig. 2. The log response ratios for the 10-s delay group as a function of the log reinforcer amount (or delay) ratios.

ratio of 1:3 was combined with a 1:3 ratio of reinforcer amounts. The results were that as the absolute durations of terminal links increased, the pigeons' preferences for the larger, more delayed reinforcers decreased so that preference actually switched from the larger to the smaller reinforcer. This decrease in preference is consistent with the present finding that rats preferred the larger reinforcer (six food pellets) under the 5-s versus 30-s delay condition, but were indifferent between one and six food pellets under the 10-s versus 60-s delay condition. The present finding suggests that either S_a or S_d changes as a function of delay. Also, S_a appeared to be equal to S_d for all but one condition (i.e., the 5-s vs. 30-s delay condition). The basis for this conclusion is that indifference was achieved in the 10-s delay series with reinforcer delay ratios of 0.17 and 6 (i.e., 10-s vs. 60-s delay) but not in the 5-s delay series with the same reinforcer delay ratios of 0.17 and 6 (i.e., 5-s vs. 30-s delay).

EXPERIMENT 2

The purpose of Experiment 2 was to find the point of indifference—the point at which a subject responded equally often on two alternatives—for the one condition of Experiment 1 that did not produce indifference (i.e., 5-s delay for one pellet vs. 30-s delay for six pellets). From these estimates for indifference, we can specify empirically the extent to which rats prefer the larger reinforcer.

Method

Subjects and Apparatus

Five male albino rats served as subjects. Of the 5 rats, 3 (R11, R12 and R13) were experimentally naive. The remaining rats had served in Experiment 1. All rats were maintained at approximately 80% of their free-feeding weights by supplemental food after each experimental session. The apparatus was the same as that used in Experiment 1.

Procedure

The basic procedure was the same as that used in Experiment 1. As in Ito and Asaki (1982), functionally equivalent combinations of amount and delay were determined by increasing a delay interval (initially 30 s) for the larger reinforcer (six food pellets) while a delay interval (5 s) for the smaller reinforcer (one food pellet) was held constant. Initially, rats were given a choice between two alternatives consisting of a 5-s delay with one food pellet and a 30-s delay with six food pellets. After choice proportions were determined under this combination of reinforcer amount and delay, the delay for the larger reinforcer was increased until preference for the larger reinforcer reached about .50. The acceptable range of values was arbitrarily designated as .45 to .55. The step size for increasing delays was 5 s. Changes in the delay for the larger reinforcer were made when the daily choice proportions satisfied the following criteria: After five sessions (and every day thereafter until the criteria were achieved), the delay was increased when (a) the mean choice proportions of these five sessions did not fall within the range of reach .45 to .55, and (b) there was no downward trend in the daily choice proportions.

The naive subjects were initially exposed to the same preliminary training as described for Experiment 1 and were then given baseline training with a combination of reinforcer amount and delay consisting of a 5-s delay with one food pellet and a 30-s delay with six food pellets. For the subjects that had served in Experiment 1, the baseline condition was given after the completion of the last condition of Experiment 1. Each daily session consisted of 30 cycles.

Results

Figure 3 shows that the mean choice proportions for the larger reinforcer declined as the delay to the larger reinforcer increased, reaching about .50. The delay for the larger reinforcer ranged between 35 s and 65 s (the mean delay value across 5 rats was 55 s). Thus, functionally equivalent combinations of reinforcer amount and delay were found for each rat.

Discussion

The present results showed that six food pellets after a delay of 55 s was functionally equivalent to a 5-s delay with one food pellet. This finding supports the results obtained in Experiment 1 that there was a strong preference for six food pellets when delays were shorter (i.e., 5-s vs. 30-s delay condition) and

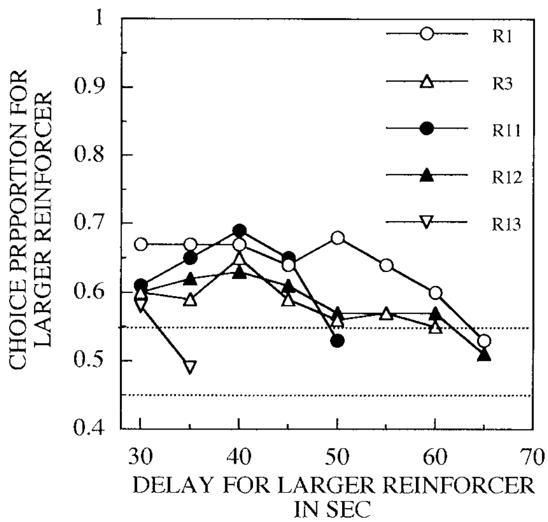

Fig. 3. The choice proportions for the larger reinforcer as a function of the delay values for the larger reinforcer. The dashed lines show the lower and upper limits of the indifference zone. The choice proportions were obtained by dividing the number of initial-link responses for the larger reinforcer by the total number of initial-link responses. The choice proportions for the baseline condition were based on the last six sessions, whereas the choice proportions during testing were based on all five sessions or the last five sessions when the condition lasted for more than five sessions.

is consistent with the choice proportions obtained under the baseline condition of Experiment 1; the mean choice proportion for the larger reinforcer across 5 rats was .61 in the present experiment, and it was .61 for the same condition in Experiment 1. As in Experiment 1, these results may reflect a difference in the sensitivities to reinforcer amount and delay, specifically, a high sensitivity to reinforcer amount or low sensitivity to reinforcer delay.

The results are also consistent with Ito and Asaki's (1982) finding that longer delays for the larger reinforcer were required to achieve indifference between two alternatives consisting of one and three food pellets. Based on their obtained transforming function, for example, the functionally equivalent delay for the larger reinforcer was 23 s (rather than the assumed delay of 15 s) when the delay for the smaller reinforcer (one food pellet) was 5 s (see their Figure 3, p. 389). Further, the results of the present Experiment 1 showed that choice proportions for the larger reinforcer (two food pellets) did not deviate from indifference. Taking these results together, it seems that functionally equivalent delays (relative to the 5-s delay with one food pellet) are increased with increases in the number of food pellets (i.e., from two, through three, to six food pellets).

The results of Experiment 2 extended the findings of Ito and Asaki's (1982) study to the situation in which a single VI-scheduling procedure rather than two independent VI schedules was used in the initial links of a concurrent-chains schedule, and also to the situation in which one and six food pellets with unequal delays were used instead of one and three food pellets with equal delays. In these conditions, functionally equivalent combinations of reinforcer amount and delay were found for all rats. Thus, these results confirmed the generality of Ito and Asaki's results and the usefulness of the present approach to specify the effects of reinforcer amount and delay by assessing points of indifference.

GENERAL DISCUSSION

The finding that indifference was achieved when the reinforcer amount and delay ratios were equal under most, but not all, conditions can be reconciled with the generalized matching law if S_a or S_d is allowed to vary across conditions. This conclusion is consistent with that offered by Rodriguez and Logue (1986). They gave pigeons a choice between several pairs of different amounts and delays of reinforcement in nonindependent concurrent schedules and found that pigeons' choices were adequately described by Equation 1, indicating that the effects of amount ratios and delay ratios are independent, as represented in Equation 1 (see also Grace, 1995).

Several studies, however, have obtained results that seem to be inconsistent with the present data. For example, studies of choice between delayed reinforcers have shown that preference for the shorter of two delays increases when the absolute size of the delays is increased (e.g., Duncan & Fantino, 1970; Gentry & Marr, 1980; MacEwen, 1972; Williams & Fantino, 1978). In a related study, Davison (1988) used a concurrent schedule to examine the effects of reinforcer frequency on sensitivity to reinforcer amount and

Table 2

Mean choice proportions for the larger reinforcer, obtained delays for the larger reinforcer, and exponent ratios (S_a/S_d) for each rat.

Subject	Choice proportion	Obtained delay (s)	Exponent ratio (S_a/S_d)
R1	.67	65	1.43
R12	.60	65	1.43
R3	.60	60	1.39
R11	.61	50	1.29
R13	.58	35	1.09
M	.612	55	1.326

found that pigeons' sensitivity for reinforcer amount decreased with increases in reinforcer frequency. Also, Ito (1985), using a concurrent-chains schedule, varied reinforcer amounts in three different conditions and found that sensitivity to variations in reinforcer amount varied depending on the durations of equal delays used in the terminal links of the concurrent-chains procedure.

As mentioned in the discussion of Experiment 1, the present results are consistent with those of Green and Snyderman (1980) and Snyderman (1983), demonstrating that in the 1:3 ratio condition, pigeons' preferences for the larger, more delayed reinforcers decreased, shifting from the larger to the smaller reinforcers when absolute delay durations were increased (i.e., from 2-s vs. 6-s to 40-s vs. 120-s delays). These results appear to be different from Ito's (1985) results, which showed that rats' sensitivity to reinforcer amount increased with increases in equal delays. There is a major procedural difference between these studies, however. Ito (1985) used equal delays, whereas in the present study as well as in the Green and Snyderman (1980) and the Snyderman (1983) studies, the delays were unequal. Therefore, it seems difficult to compare the present results with Ito's results directly. Concerning the effects of equal and unequal delays, White and Pipe (1987) provided relevant data; they arranged a self-control choice situation by using a concurrent-chains schedule and found that sensitivity to reinforcer amount (S_a) increased when the absolute size of unequal delays was increased. These results are not directly comparable to those of the present studies, however, because the delay ratios were also decreased in their study. Future research on this issue should attempt to assess more adequately sensitivity to reinforcer amount as a function of the absolute size of unequal delays.

The effects of reinforcer amount and delay can be dealt with by using a relative measure of the ratio of exponents (S_a/S_d) in the generalized matching equation (e.g., Green & Snyderman, 1980; Logue et al., 1984). Given $R_1 = R_2$ and $k = 1$ (no response bias), and rearranging Equation 1, we obtain

$$\frac{S_a}{S_d} = \frac{\log\left(\frac{D_1}{D_2}\right)}{\log\left(\frac{A_1}{A_2}\right)}, \tag{3}$$

where S_a and S_d represent exponents for the reinforcer amount and delay, D is the delay to reinforcer, and A is the reinforcer amount.

Based on the obtained points of indifference, the relative measure of the ratio of exponents (S_a/S_d) can be obtained for each rat of Experiment 2. This measure for each rat is shown in Table 2, along with the choice proportions for the larger reinforcer and the obtained delays for the larger reinforcer. The obtained values of the ratio of exponents ranged from 1.09 to 1.43; the mean ratio of exponents across 5 rats was 1.33. These results show that rats are more sensitive to reinforcer amount than reinforcer delay under the 5-s versus 30-s delay condition. For other conditions, the ratio of exponents has to be 1.0, because choice proportions showed indifference between two alternatives. Further, a similar ratio of exponents can be obtained from the Ito and Asaki (1982) study; based on the obtained functionally equivalent delays with the larger reinforcer, for each delay with the smaller reinforcer, this measure decreased from 1.39, through 1.19, to 1.0, and then to 0.78 with increases in delays for the smaller reinforcer (from 5, through 10, to 20, and then to 40 s). Thus, it seems that the relative measure of the ratio of exponents varies depending on factors such as delay value and training history with and without exposure to fading procedure.

In conclusion, the present study demonstrated that the indifference point method proved to be useful in assessing the relation between sensitivity to reinforcer amount and delay in a self-control choice situation. The results of the present study as well as those from other research on choice in a self-control choice situation are consistent with the generalized matching equation with different sensitivities to reinforcer amount and delay. Further, the present results suggest that the reversal of choice is simply due to changes in the relative sensitivities.

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